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Ship Material Readiness

by

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A Division of CNA Hudson Institute

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This research memorandum evaluates ship material condition on the basis of mission-degrading casualty reports. Tobit models estimate the effect on ship material readiness of such resource variables as manning, crew stability, months since last overhaul, steaming hours, and length of time commanding officer has had ship command. Identical models are used for Knox, Spruance, and Adams ship classes. For all three classes, the most important influences are related to manning.

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ABSTRACT

This research memorandum evaluates ship material condition on the basis of mission-degrading casualty reports. Tobit models estimate the effect on ship material readiness of such resource variables as manning, crew stability, months since last overhaul, steaming hours, and length of time commanding officer has had ship command. Identical models are used for *Knox*, *Spruance*, and *Adams* ship classes. For all three classes, the most important influences are related to manning.

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CONTENTS

INTRODUCTION

Explaining a substantial proportion of the variation in the material condition of specific ships will probably never be possible. Many factors affect the material condition of suface ships. Some of these factors are too difficult to measure precisely; others may be inherently unmeasurable. Mission-degrading equipment failures can be caused by errors made on the ship, in a factory where the equipment is produced, or in a shipyard during an overhaul. In addition, the maintenance and operating practices vary substantially from ship to ship, making it unlikely that analytic methods used to predict the material condition of aircraft will be as successful when applied to ships.

However, even if one cannot explain precisely why one ship has excellent material condition and another is mission degraded, it may be possible to isolate systematic factors that, on average, are associated with better material readiness at the platform level. Such analysis is useful. Identifying policy-amenable factors should aid in improving the average material readiness of the fleet.

Isolating such systematic relationships between ship resources and ship material readiness is difficult for at least two additional reasons. First, there appear to be inherent ship differences. Some ships always appear better than average and others always worse than average. This possibility has generally been ignored in past analyses. Second, at a given moment, active fleet ships tend not to differ greatly in terms of the resources they possess. For example, the differences in manning or skill mixes are small, and this fact has made it difficult to identify analytically the effects of manning on readiness. Perhaps if more sensitive measures of manning levels—other than counts of bodies relative to requirements—could be constructed, the importance of better manning on ship material condition could be estimated more precisely.

This research memorandum attempts to assess the importance in analyses of ship material condition of controlling for persistent "ship effects" (i.e., intrinsic to a ship but independent of resource levels). In addition, it examines the importance of controlling for possible differences among ships' commanding officers (COs) in the reporting of the material condition of their ships. In doing so, it estimates the relationship in a functional form that permits the effects of additional resources on ship material condition to vary, depending on the level of other resources currently available to the ship.

The general findings are as follows:

- Estimates of the impact of resources on ship material condition can be improved if the estimates are conditioned on the ship and on the few COs who systematically report fewer (or more) casualties.

- Estimates can be further improved by employing a functional form suited to the particular measure of ship material condition analyzed.

In this context, manning, weighted by relative pay as a proxy for the relative productivities of personnel in the different paygrades, proves to be both importantly and significantly related to the material condition of surface ships. Moreover, the data suggest that the larger the proportion of the crew new to the ship, the worse the material condition of the ship. Some support is also found for the hypothesis that the longer a CO has had command of a particular ship, the better the material condition of that ship.

DATA

Monthly data for deployed ships in the *Knox* and *Spruance* classes were chosen for the initial analysis. Because manning, employment, and maintenance patterns differ substantially among active and reserve ships, the analysis was restricted to ships that were part of the active fleet.[1] To be certain that a ship effect and not a deployment effect was being captured, it was further decided to restrict the sample to ships that were deployed for at least two distinct time periods between 1981 and 1986. Each observation is thus a ship deployment month. After the analysis on *Knox* and *Spruance* class ships was completed, the same models were applied to the *Adams* class (DDG-2s).

Ship material condition is evaluated on the basis of mission-degrading casualty reports (CASREPs).[2] C3 and C4 CASREPs indicate that an equipment deficiency exists in mission-essential equipment that either causes a major degradation, but not loss of a mission area (C3), or causes loss of a mission area (C4). CASREPs are not filed if it is expected that the deficiency can be corrected within 48 hours [2]. Because C3/C4 CASREPs reflect at least a major degradation of a mission area, it may be more appropriate to view measures based on these serious CASREPs as measures of ship material readiness rather than the more general descriptor, ship material condition.

Two measures of ship material readiness were constructed. The first is the percentage of days in the month that the ship is free of C3 and C4 CASREPs (PCTFREE). The second is CASDAYs, the sum of all the days in the month in which each piece of equipment was in C3 or C4 status. For example, if three pieces of equipment were in C3 or C4 status for an entire 30-day month, CASDAYs would equal 90 for the month. For all ship classes, these measures of material readiness for individual ships exhibit substantial variation around their class average.

Table 1 provides a brief description of the variables used in the analysis as well as information about the data from which these variables were either extracted or constructed. There were 599 observations for the *Knox* class, 491 for the *Spruance* class, and 351 for the *Adams* class that fulfilled the criteria for sample inclusion.

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1. Ships that became part of the Naval Reserve Fleet (NRF) in the time period are included in the analysis until they are part of the NRF.
2. See [1] for an earlier study of CASREPs on particular equipment maintained on surface combatants by personnel in six ratings.

Table 1. Variable means, standard deviations, and data source

	Mean (standard deviation)			
Variable	FF-1052	DD-963	DDG-2	Variable description and source of data
MSO	34.02 (15.60)	32.77 (15.55)	25.40 (12.03)	Months since last overhaul (Ship Employment Histories)
PACIFIC	.49 (.50)	.45 (.50)	.53 (.50)	Value of 1 if ship in PACFLEET (Ship Employment Histories)
SH_UNDER in hundreds	4.29 (1.68)	4.21 (1.77)	4.18 (1.74)	Steaming hours underway for month (ship fuel and steaming hours data)
PNEW3	9.91 (3.67)	9.63 (3.40)	10.44 (3.67)	Percentage of enlisted crew new to ship this quarter [Defense Manpower Data Center (DMDC) unit identification code (UIC) manning data]
MANREQ	81.98 (4.64)	92.06 (5.36)	82.48 (4.29)	Enlisted manning relative to M+1 manning requirements. See text for more complete description (DMDC UIC manning tapes and billet file data)
TIME_CO	13.57 (7.95)	14.22 (8.49)	14.31 (8.52)	Number of months, including this month, CO has been CO of this ship (Officer Master Tape)
GEF	.50 (.15)	.52 (.13)	.48 (.14)	Gross effectiveness, see text (3M data)

Information on deployments (which was necessary to determine the relevant ships for analysis) and the date of the last overhaul come from the Ship Employment History file.[1] A ship is considered deployed when a deployed record is found on the Ship Employment History or when it operates in ocean areas P4 (WestPac), P6 (Indian Ocean), A6 (Mediterranean), or A7 (Persian Gulf). A deployment begins when a ship leaves its homeport (or an overhaul) and ends when the ship returns to port at its homeport (or enters overhaul).[2] Months since last overhaul

1. See [3] for a more complete description of the Ship Employment History file.
2. These two requirements (a deploy record or operation in one of the above four ocean areas) appear to be equivalent. Ships whose homeport is in one of the four deployed ocean areas were excluded from the analysis because it was believed that their continuous deployment status was quite different from other deployments.

(MSO) is simply the number of months since the ship was last in an overhaul activity (unit construction, conversion, modernization, or overhaul).[1]

The variable, PACIFIC, indicates those ships in the Pacific Fleet, roughly half the sample. The variable, SH_UNDER, taken from the Ship Fuel and Steaming Hours Data, is underway steaming hours for the ship in the month. All ship classes averaged slightly over 400 underway steaming hours per month of their deployments.

Two variables on enlisted manning are used in the analysis. PNEW3 is the percentage of the ship's enlisted crew that was not assigned to the ship three months earlier.[2] New enlisted crew averages about 10 percent. MANREQ is a measure of the ship's enlisted manning relative to the manning requirements for the ship at mobilization (M+1 requirements). It is not, however, simply a count of the enlisted manning relative to the requirements. Because higher paygrade personnel are presumably more productive than those in lower paygrades, a variable that reflects the mix of paygrades was developed to better capture the effects of manning on material condition.

In the absence of established measures of the relative productivities of personnel in different paygrades, it was decided to use basic pay to weight the relative productivities.[3] If P_i is the average basic pay for the ith paygrade, N_i is the number of personnel in that paygrade, and R_i is the number of M+1 personnel required in the paygrade, the manning variable, MANREQ, is defined as follows:

$$MANREQ = \frac{\sum_{i=1}^{9} P_i N_i}{\sum_{i=1}^{9} P_i R_i} .$$

The enlisted manning data come from a quarterly UIC manning file that the Defense Manpower Data Center (DMDC) constructs for CNA, whereas the M+1 requirements data come

1. Selected restricted availabilities (SRAs) are not included in the overhaul definition. Some of the newer *Spruance* class ships have not yet had a major overhaul. For them, MSO is the months since the ship was commissioned.

2. Because the Defense Manpower Data Center (DMDC) data used to construct this variable are only available as end-of-quarter snapshots (December, March, June, and September), this variable has the same value for three months, i.e., the new crew value calculated from the September/December match is used for the December, January, and February observations.

3. Because basic pay depends on both length of service and paygrade, it was necessary to find the average length of service for personnel in the different grades. The September 1986 Enlisted Master Record file was used to calculate average length of service for each paygrade. Using basic pay as the productivity weight yields the following relative productivities when the pay of E-9s is normalized to 100: E-1s and E-2s = 32, E-3s = 35, E-4s = 42, E-5s = 48, E-6s = 60, E-7s = 71, and E-8s = 83. For example, the average E-3's basic pay is 35 percent of the average E-9's basic pay.

from the billet file.[1] This definition of enlisted manning yields a mean of 82 for the FF-1052s and DDG-2s and 92 for the DD-963s. The standard deviation is between 4 and 5.

The variable, TIME_CO, is the number of months that the ship's CO has had ship command. The COs for all ship classes had averaged about 14 months on the job at the mean of the observations, but the standard deviation is about 8 months. This variable was constructed from the Officer Master File.

The GEF variable is the percentage of all requests for parts that the ship's stockroom was able to fill from stock on hand that month. It is calculated, from the 3-M Parts data, by the Navy definition of gross effectiveness. It is the allowance and non-allowance list material issued from the storeroom when requested divided by all the storeroom requests that month (for allowance, non-allowance, and not carried parts).

Finally, a vector of control variables was constructed for each ship in the data set. These variables assume the value of 1 if the observation in question is for that particular ship, otherwise they assume the value of zero.[2] The analysis used 35 ships from the *Knox* class, 25 from the *Spruance* class, and 20 from the *Adams* class.

Because there is concern that some COs may have different policies about CASREPs (some may liberally file CASREPs to speed the flow of supplies while they are on deployment, whereas others may be reluctant to report CASREPs), vectors of control variables were also created for the ships' COs. As the term—control variables—suggests, both the ship and CO variables are intended to free the observations of systematic ship and CO variance so that the true effect of the resource variables in explaining ship material readiness can be observed more clearly.

MODEL ESTIMATION

The percentage of time free of serious CASREPs (i.e., PCTFREE) is a variable that ranges from 0 to 100 percent for each month. Many of the observations, in fact, take on the limit values of either 0 or 100. For the *Knox* class, 58 of the 599 observations for PCTFREE were 0, and 214

1. CNA does not have accurate billet file data before 1983. Thus, the M+1 requirements (necessary for the denominator of the manning variable) for the years 1981 and 1982 have been assumed to be identical to those for 1983. Some experimentation was done using a manning variable unweighted by M+1 requirements (manning is available for the entire 1981 to 1986 period). Although the empirical results were similar, the fit was slightly better with the manning variable described in the text. Thus, it was decided to use that variable, even though requirements data were not available before 1983.
2. These control variables can be understood as changes in the intercept—in effect, they allow each ship to have its own intercept. In the econometric literature, such models are often called fixed-effect models.

had a PCTFREE value of 100. For the *Spruance* class, the corresponding numbers are 62 and 210 (out of 491 observations). In the *Adams* class, 91 of the 351 monthly observations were 0 percent time free of C3/C4 CASREPs, and 103 observations were 100 percent time free.

Although PCTFREE is bounded by 0 and 100, the underlying material condition of a ship is not really so bounded. Simply because two ships are both at 100 percent time free of serious CASREPs does not mean they are necessarily in identically equal material condition. Moreover, at the bound of 100 percent, PCTFREE cannot show the effects of increases in the ship's resources, nor can it show the effects of reductions in resources when a ship is at 0 PCTFREE.

To prevent obscuring the effects of resource variables on ship material condition, the estimation strategy must take into account the bounds on this measure of ship material condition.[1] A Tobit estimator can allow for both upper and lower bounds; it estimates an S-shaped curve between the two limits.[2] Such an S-shaped curve is shown in figure 1. Unlike the constant marginal effect assumed when using ordinary least squares (OLS), the Tobit allows for different marginal changes in readiness per additional units of resources. That is, the non-linear Tobit specification estimates differential effects for the explanatory variables, depending on where the function is evaluated.[3]

Observations of 0 CASDAYs cannot reflect possible differences in the material condition of ships (no serious CASREPs in a month can reflect very good to truly excellent material condition.) Likewise, this variable cannot capture the effect of increasing resources when a ship is already at 0 CASDAYs for the month. As with PCTFREE, CASDAYs can be appropriately estimated with a Tobit model, using, in this case, a single limit at zero.[4]

1. An ordinary least-squares regression is particularly inappropriate because it would, in some cases, predict a value less than 0 or more than 100 for PCTFREE.

2. See [4] for Tobin's first discussion of this estimator in the regression context and appendix A for a more complete discussion of the differences in ordinary least squares and Tobit estimation in the context of bounded observations.

3. This functional form is additionally appealing because it exhibits positive, but diminishing, returns to additional resources as a ship approaches the bound of 100 percent time free of C3/C4 CASREPs.

4. Other statistical concerns remain, however. In particular, one econometric problem likely to be a factor in this research is autocorrelation (or serial correlation) of the disturbances across periods. The type of autocorrelation in these data, however, does not lend itself to readily available statistical packages that deal with autocorrelation. Unlike the usual time-series autocorrelation where, for example, one month's employment is highly correlated with the next month's employment rate, the problem here is autocorrelation of the errors within the time period of each ship's deployment. For the *Knox* class, there are over 70 deployments. Thus, there are over 70 separate sets of probably autocorrelated residuals. As a general test of the impact of autocorrelation, the models were reestimated with PCTFREE (or CASDAYs) in the prior month as an additional explanatory variable. Although the coefficient on these lagged terms was always highly significant, it generally had only a minor effect on the other explanatory variables. Because this test does not address the problem of multiple sets of autocorrelated errors, the results are not reported. Reference [5] provides a possible way to correct for such autocorrelation, but such work was not possible within the time frame of this study.

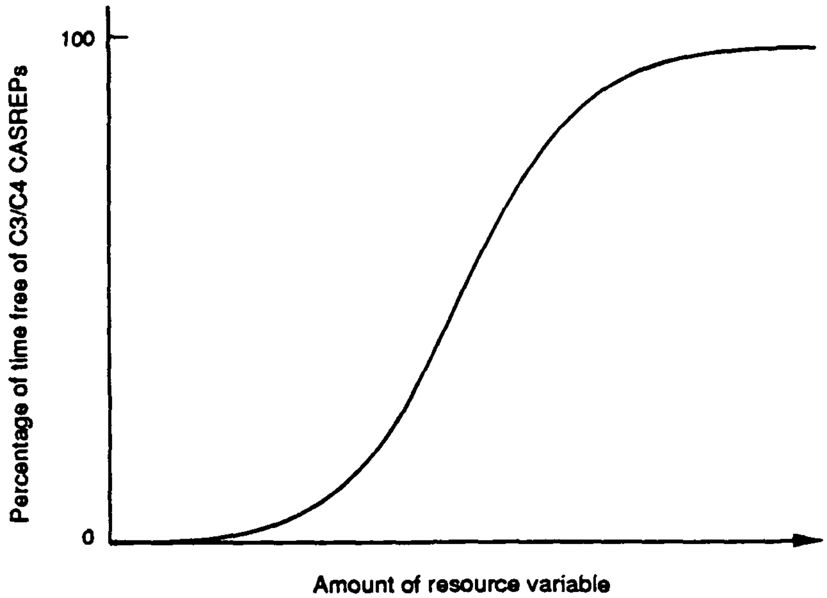

Figure 1. Example of a two-limit Tobit function

In addition, OLS estimates for CASDAYs would not be appropriate because the bunching of observations at the limit violates one of the necessary assumptions for OLS models. In fact, OLS estimates will be biased, in this case understating the impact of the explanatory variables around the mean of the data (see appendix A for details).

STATISTICAL ESTIMATES AND IMPLICATIONS

Identical models (i.e., using the same explanatory variables and identical model specifications) were used for all three ship classes; in several cases, the estimated effects of a variable differed considerably from one class to the other. For example, the time since overhaul (modeled to capture both immediate and long-term effects of overhaul) was very important in the CASREP patterns on DD-963s. For the *Spruance* class ships, PCTFREE declines after an overhaul and levels off at 20 months. It was not significant for FF-1052s or DDG-2s. This difference suggests that the determinants of CASREPs for each class are meaningfully different from one another in some respects.[1]

1. The two classes are treated separately because regression estimates that pooled data from both classes could be misleading even if the models included a control variable for ship class. A standard control variable approach would allow the mean of the dependent variable to differ from class to class, but it would not permit the marginal effects of independent variables to differ from class to class. Since this appears to be important for these classes, separate regressions were used.

More time free of serious CASREPS is associated with better manning relative to requirements for ships in all three classes, as is a longer tour of the CO for ships in the *Knox* and *Adams* classes. Less time free of serious CASREPs is associated with higher proportions of new crew for *Spruance*, *Knox*, and *Adams* class ships. Other statistically significant findings include positive relationships between underway steaming hours and ship material condition for the *Adams* class and higher gross effectiveness rates and better ship material condition for the *Knox* class.

Appendix B provides formal statistical results and a detailed discussion of these results. Table B-1 gives the estimated coefficients for the FF-1052s, and tables B-2 and B-3 provide the corresponding results for the DD-963s and DDG-2s for PCTFREE. The estimates for CASDAYs are in tables B-4, B-5, and B-6. Each of the six tables provides estimates of the model for three specifications:

- Specification 1: controls for ship and CO effects
- Specification 2: controls for ship effects only
- Specification 3: no controls for CO or ship effects, only resource variables.

The tables also include results for OLS estimation. Despite their bias, these estimates can be useful. Coefficient estimates from OLS models can be readily interpreted, unlike Tobit estimates, which need to be transformed by normal densities and distributions (see appendix A). In addition, the likely direction of the bias (but not the magnitude) is known. Coefficients derived from OLS almost certainly overstate the true effects of the explanatory variables near the bounds of 0 and 100 and understate the true effects for values not near the bounds.

Two general points should be made before a fuller discussion of the empirical findings. First, in all specifications for PCTFREE, the data appear better represented by the Tobit equation than by the OLS. For the CASDAYs specifications, the Tobit estimates are quite similar to the OLS estimates except near the bound of 0 CASDAYs when the linear regressions clearly overstate the impact of the explanatory variables. Second, the model exhibits more explanatory power when the ship and CO control variables are included in the specification.[1] (Of more than 100 COs in each ship class, only 10 exhibited significantly different behavior, such that their CO control variables were included in the estimated equation.[2]) Of more interest, however, is whether inclusion of these control variables improves understanding of the effect of variables of

1. This is most easily seen by examining the adjusted R^2 values for the OLS equations. For example, for the 1052 class ships (table B-1), the adjusted R^2 for PCTFREE increases from 0.04 to 0.14 when the 35 ship control variables are added to the model and to 0.22 when the final 10 CO control variables are added. (True R^2 values cannot be computed for Tobit equations.) More formal tests of the significance of the additional variables are summarized in table B-8.
2. See appendix B for a discussion of how the CO control variables were defined.

interest to the Navy (e.g., manning, steaming hours, time since overhaul) on the material condition of these surface ships. The results suggest the following:

- Including the ship control variables substantially increases the explanatory power.
- Including both the ship and CO control variables further increases the explanatory power.
- The inclusion of such control variables can improve understanding of the effects of resource variables on material readiness.

In the context of a model that controls for ship and individual CO effects, table 2 describes the predicted *average* differences in percentage of time free of C3/C4 CASREPs associated with different resource levels for the individual ships. It should be understood that the actual PCTFREE for an individual ship may be higher or lower than the average because of characteristics and activities of the ship not included in the model.

At the mean values for all the explanatory variables, the models for both the *Spruance* and *Knox* class ships predict an average of 70 percent time free (51 percent time free for the *Adams* class). Varying manning relative to requirements (MANREQ) just one standard deviation, however, substantially changes the predicted time free. For the *Knox* class, a one-standard-deviation change results in about a 6-percentage-point change in PCTFREE. For the *Spruance* class, the change is larger: MANREQ one standard deviation above its mean is associated with a value of PCTFREE almost 13 percentage points higher, whereas a similar size decrease in MANREQ lowers predicted PCTFREE by over 15 percentage points.[1] Each of the relevant coefficients is statistically significant at the 0.005-percent level and robust across all model specifications (see tables B-1, B-2, and B-3).

A one-standard-deviation change in MANREQ is a 6-percent change in manning relative to requirements. It is important to remember, however, that MANREQ is not simply a count of the ship's enlisted manning relative to M+1 requirements. Instead, it is a weighted count of enlisted manning relative to a weighted count of M+1 requirements, where the weights are the average basic pays of the personnel in the different paygrades. Thus, two E-3s have about the same weight as an E-7; an E-9 counts about the same as two E-5s; and an E-3 and an E-5 are worth about the same as an E-8. A 6-percent increase in the personnel in each paygrade (holding requirements constant) would increase MANREQ by 6 percent, but manning could also be increased by 6 percent in a variety of other ways. And, because of the larger weights given personnel in higher paygrades, a 6-percent improvement in manning requires different numbers of additional personnel depending on their paygrades.

1. The change is not symmetric because the estimated relationship is nonlinear.

Table 2. Percent time free of C3/C4 CASREPs (PCTFREE): predicted impact of resource variables from full-specification Tobit model

Resource level	Predicted average PCTFREE by ship class		
	Knox (FF-1052s)	*Spruance* (DD-963s)	*Adams* (DDG-2s)
Predicted PCTFREE for means of all variables	70.49	69.92	51.01
Changes from the overall mean prediction			
MANREQ[a]			
One *SD* above mean	76.36	82.50	63.16
One *SD* below mean	64.06	54.46	37.78
PNEW3[a]			
One *SD* above mean	66.18	62.82	45.74
One *SD* below mean	74.44	76.27	56.26
Months since overhaul (or commission)[a]			
24	_[b]	75.31	_[b]
36	_[b]	72.57	_[b]
48	_[b]	71.64	_[b]
TIME_CO[c]			
One *SD* above mean	72.90	_[b]	68.76
One *SD* below mean	68.01	_[b]	33.04

NOTE: *SD* = standard deviation.

a. Coefficients are statistically significant at 0.005 level.
b. Coefficients are not statistically significant.
c. The coefficient is statistically significant at 0.10 level for *Knox* class and 0.005 level for *Adams* class.

Although the manpower variable, MANREQ, appears to capture the positive effect of better manning on ship material condition, it does not provide the Navy with any new insights on how to man ships more cost-effectively. This is because the relative productivities of personnel in the different paygrades are not estimated, but instead are constrained to be the relative basic pays. What the variable does suggest, however, is that the relative pay of personnel in the different paygrades is probably a reasonable proxy for relative personnel productivities and that the material condition of surface ships is significantly and positively related to MANREQ.[1] Thus, if onboard manning costs are cut (either by reducing personnel because of a reduction in the

1. MANREQ, by definition, is the ratio of the sum of the basic pay of enlisted personnel on board divided by the sum of the basic pay of personnel required at M+1.

shipboard manning allowance or by reducing the percentage of the allowance that is manned), the material condition of the ship would be expected to worsen.

A larger percentage of enlisted personnel new to the ship also degrades ship material condition. On average, about 10 percent of a ship's enlisted crew was not assigned to that ship in the previous quarter. A one-standard-deviation change for PNEW3 for these deployed ships is about 4 percent. Thus, table 2 shows that the predicted average impact for ships in *Knox* class with only 6 percent new crew (and other variables at their means) would be 74 percent time free of C3/C4 CASREPs; otherwise comparable ships, but with 14 percent new crew, are predicted to average only 66 percent time free. For the *Spruance* class, the predicted average differences are even larger: PCTFREE is 63 with 14 percent new crew and 76 with 4 percent new crew. The results for the *Adams* class were 46 percent time free one standard deviation above the mean for new crew and 56 percent time free for one standard deviation below.[1]

For the *Spruance* class ships, months since overhaul (or commissioning date for ships that had not yet had an overhaul) is also statistically significant, although the magnitude of the effect is not large. At the mean of the observations for the other variables, percentage of time free increases slowly as months since overhaul (or commissioning date) increases. At about 36 months, the effect levels off.

For *Knox* class ships, there are small, but statistically significant, results for TIME_CO and GEF.

- Moving from one standard deviation below the mean months of CO ship command to one standard deviation above the mean (from about 6 months to over 21 months) increases the PCTFREE by about 5 percentage points.

- Changing the probability of finding the required spare parts (from one standard deviation below the mean to one standard deviation above the mean) changes the PCTFREE by almost 6 percentage points.[2]

When the model was applied to DDG-2s, more underway steaming hours and a longer time as CO were also found to have significant positive effects on ship material condition.

1. PNEW3 reflects overall enlisted crew turnover. Further work could explore turnover in more detail. Specifically, the effects of turnover may vary by paygrade, LOS, and rating.
2. It is perhaps somewhat surprising that the GEF variable is able to capture any of the variation in PCTFREE. The vast majority of spare parts are requested for minor and regular repairs and have little to do with major degradations in the material condition of the ship reflected by C3 and C4 CASREPs.

Table 3 tabulates the results for CASDAYs. Variables that increase the PCTFREE decrease the number of CASDAYs. The estimation seems robust because the same variables are statistically significant in both the PCTFREE and CASDAYs models:

- As manning relative to M+1 requirements increases from one standard deviation below the average of the observations to one standard deviation above,
  - Average CASDAYs decrease by almost 5 for the *Knox* class.
  - Average CASDAYs decrease by almost 14 for the *Spruance* class.
  - Average CASDAYs decrease by almost 17 for the *Adams* class.
- As the percentage of new crew increases from one standard deviation below the average of the observations to one standard deviation above,
  - Average CASDAYs increase by over 3 days for the *Knox* class.
  - Average CASDAYs increase by almost 6 days for the *Spruance* class.
  - Average CASDAYs increase by almost 11 days for the *Adams* class.
- As the number of months since overhaul (or commissioning date) increases for the DD-963s, average CASDAYs slowly decrease.
- As the CO's experience increases, average CASDAYs fall for the *Knox* class and the *Adams* class.
- As steaming hours increase for the *Adams* class, average CASDAYs decrease.

The explanatory variables used in the various specifications represent only a small subset of the factors that might reasonably be expected to influence the level of CASREPs on a ship. It is not surprising, therefore, that much of the variation in CASREPs is not explained in any of the models.[1] Some of the explanatory variables, however, consistently generate statistically significant impacts on average ship material condition. For this reason, it is possible to say, with a high level of confidence, that manning levels and rotation policies significantly influence average CASREP rates despite the fact that models do not predict a particular ship's CASREP rate in a given month with much accuracy.

1. For the six full model specifications, the amount of the variation explained in the linear regressions varied between 21 and 46 percent.

Table 3. C3/C4 CASDAYs: predicted impact of resource variables from full-specification Tobit model

Resource level	Predicted average CASDAYs by ship class		
	Knox (FF-1052s)	*Spruance* (DD-963s)	*Adams* (DDG-2s)
Predicted CASDAYs for means of all variables	11.90	11.65	23.41
Changes from overall mean prediction			
MANREQ[a]			
One *SD* above mean	9.85	5.94	19.49
One *SD* below mean	14.17	19.80	36.11
PNEW3[a]			
One *SD* above mean	13.64	14.63	31.80
One *SD* below mean	10.29	9.07	22.99
Months since overhaul (or commission)[a]			
24	–[b]	8.70	–[b]
36	–[b]	10.10	–[b]
48	–[b]	12.73	–[b]
TIME_CO[c]			
One *SD* above mean	10.75	–[b]	18.75
One *SD* below mean	13.11	–[b]	37.10

NOTE: *SD* = standard deviation.

a. Coefficients are statistically significant at 0.005 level.
b. Coefficients are not statistically significant.
c. The coefficient is statistically significant at 0.05 level for *Knox* class and 0.005 level for *Adams* class.

The results presented in tables 2 and 3 are derived from the coefficients of the Tobit models. They are point estimates of the PCTFREE or CASDAYs for a ship that has its explanatory variables at the levels indicated. The actual PCTFREE for such a ship might be higher or lower than the prediction, depending on the relevant characteristics and activities of the ship that are not included in the models.

Table 4 addresses the likely variation in PCTFREE for *Knox* class ships.[1] The results in this table are based on the assumption that the coefficients from the Tobit estimates are correct, but other factors that cause variation in PCTFREE continue to vary, causing the actual values of

1. Corresponding results for *Spruance* and *Adams* class ships are in table B-7.

PCTFREE to vary above and below the point estimates.[1] The leftmost column indicates different values of the explanatory variables. As in table 3, the explanatory variables are held at their mean values with one resource variable shifted by one standard deviation. The second column lists the estimated odds of a ship having more PCTFREE than the class average, given that the ship has the levels of explanatory variables listed in the first column.

Table 4. Predicted distribution of PCTFREE for changes in manning and crew rotation for FF-1052s (predicted mean PCTFREE = 70.5)

Resource level	Predicted value: Ships with above-average PCTFREE for class (%)	Predicted value: Range of PCTFREE for half of all ships
Predicted PCTFREE for means of all variables	50	51-91
MANREQ		
One *SD* above mean	58	57-97
One *SD* below mean	42	44-84
PNEW3		
One *SD* above mean	44	46-87
One *SD* below mean	55	55-95

NOTE: *SD* = standard deviation.

For example, the top row of table 4 reports the results for FF-1052s with all explanatory variables at their means. The second column indicates that such a ship would have a 50-percent chance of having PCTFREE above average for the class (and a 50-percent chance of PCTFREE below average). The second and third rows show the values for ships with manning one standard deviation above and below the mean, respectively. The model predicts that a ship with manning one standard deviation better than average would have a 58-percent chance of having a higher than average PCTFREE, whereas a ship with manning one standard deviation below average has only a 42-percent chance of above-average PCTFREE.

In the final column, a range of PCTFREE values is listed. The top row of table 4 shows that the model predicts that half the FF-1052s with all explanatory variables at their means would have PCTFREE between 51 and 91 percent. With manning one standard deviation above its mean, half the ships are predicted to have PCTFREE between 57 and 97.

1. Table B-8 presents confidence intervals of average PCTFREE for the OLS specifications.

SUMMARY OF FINDINGS

Taking the statistical results as a whole, it appears possible to explain a reasonable portion of the variation in serious CASREPs for each class of ships, but only if controls for both individual ships and for the small number of COs who deviate significantly from the norm are included.

For all three classes, the most important influences found were related to the manning of the ship. The higher the percentage of M+1 requirements, the fewer CASDAYs and the larger the PCTFREE. For example, the Tobit model estimates that, on average, a one-standard-deviation increase in MANREQ at the mean would increase time free of CASREPs by 6 percentage points for FF-1052s, 13 percentage points for DD-963s, and 12 percentage points for DDG-2s.

The other manning variable, percentage of the enlisted crew that had been with the ship for three months or less, was also significant. The larger the proportion of new crew, the more CASDAYs and the lower the PCTFREE for both classes. An increase of one standard deviation in PNEW3 was associated with a 4-percentage-point decrease in average PCTFREE for FF-1052s, a 7-percentage-point decrease for DD-963s, and a 5-percentage-point decrease for DDG-2s. Again, these estimates are based on the fully specified Tobits evaluated at their means. Both the manning requirements and new crew effects were significant in all six of the fully specified models and in most of the other specifications.

The estimates for the effects on CASREPs of steaming hours, months as CO, and gross effectiveness were less consistent. A larger TIME_CO appears to result in some significant improvement for the FF-1052s and DDG-2s, at least in the fully specified models, but virtually none for the DD-963s. Whether these results reflect some difference between the classes, or the COs, or are simply artifacts of the samples used is unknown. The estimates of SH_UNDER and GEF were generally not significant. The effects of being in the Pacific Fleet were only slightly better. The Pacific was fairly consistently associated with higher PCTFREE and fewer CASDAYs, but the coefficients were not significantly different from zero.

Time since last overhaul or commission was significant only for the *Spruance* class and requires a more detailed examination than was practical for this study. It is possible that the time since commission has an important effect for new ships but that time since last overhaul has little effect. Without additional research, however, this idea is simply speculation.

REFERENCES

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[3] CNA Research Memorandum 86-178, *Ship Employment Histories and Their Use*, by Karen N. Domabyl and Patricia A. Reslock, Jul 1986 (27860178)

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1. The number in parentheses is a CNA internal control number.

APPENDIX A

CHARACTERISTICS OF ORDINARY LEAST SQUARES (OLS) AND TOBIT MODELS

APPENDIX A

CHARACTERISTICS OF ORDINARY LEAST SQUARES (OLS) AND TOBIT MODELS

Both OLS and Tobit models treat the dependent (or left-side) variable as a function of the various independent (or right-side) variables. The coefficient estimated for each right-side variable (denoted β_i) indicates the impact of a change in the value of variable i on the dependent variable. Where Tobit and OLS differ is in the functional forms of the relationships.

OLS ESTIMATES

In the case of OLS, the estimated impact of a given change in any independent variable must be constant regardless of the value of the dependent, or other independent, variables. For example, the OLS coefficient on TIME_CO is –0.178 in one of the specifications for CASDAYs for the 1052 class. The model suggests, therefore, that one additional month as CO will reduce CASDAYs in a month by 0.178, regardless of the number of months already spent as CO, and regardless of the levels of the other independent variables.

For many relationships, this is an appropriate specification. For example, if one wished to estimate the weight of an aircraft, each additional crew member raises the weight of the aircraft by about 170 pounds. This applies regardless of the number of the crew members or the value of other independent variables, such as the type of plane. But the estimation of the percentage of time free of CASREPs (or number of CASDAYs) does not seem suited to this sort of specification for at least three reasons.

First, the possible values for percentage of time can only vary between 0 and 100. Thus, if a ship were 99 percent time free, nothing could possibly increase the time free by more than one additional percentage point.

Second, the effects of changes in many of the independent variables are likely to vary with the levels of those variables. One might expect, for example, that an additional month's experience as CO would have a larger impact when the officer is new to the ship than when he has been CO for an extended period.

Third, the impact of a change in one of the independent variables may depend on the level of other independent variables. For example, the effects of additional steaming hours with a full crew might be very different from the effects with a skeleton crew.

Of the three, the problem of the observations being bounded at 0 and 100 percent is probably the most serious. Figure A-1 shows a hypothetical distribution where a large number of

observations are found at each of the two bounds.[1] The particular distribution in the figure is commonly referred to as S-shaped. It is important to remember that the underlying material condition of the ships is not bounded, but the proxies used are bounded. For this reason, PCTFREE may be a reasonably good indicator of material condition between the bounds, but it clearly breaks down at either bound.

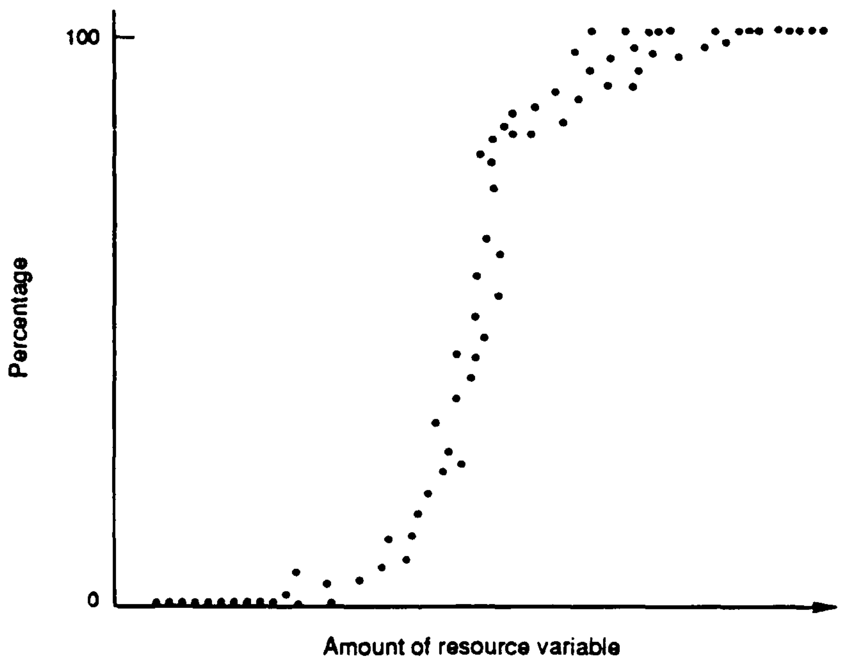

Figure A-1. Typical S-shaped distribution

The fact that a large number of observations are at the bounds strongly suggests the same sort of S-shaped relationship between the measure of material condition and the individual right-side variables. Using OLS to model such a relationship will generate biased results. Figure A-2 shows the results of OLS estimates of an S-shaped relationship between a hypothetical independent variable (denoted X_i) and PCTFREE. The solid S-shaped curve represents the true function, whereas the broken lines represent two different OLS estimates. In one case, OLS is calculated using all the available data points; in the other case, only those observations not at either limit are used.

1. A distribution of this sort is similar to the actual pattern of PCTFREE for the ship classes examined. The problem is not as serious in the case of CASDAYs, where the only bound is at zero, but a large number of ship-months are still found at that bound. In fact, all observations at 0 CASDAYs are also observations at 100 percent time free. Thus, the problem of censored data must be addressed in both models.

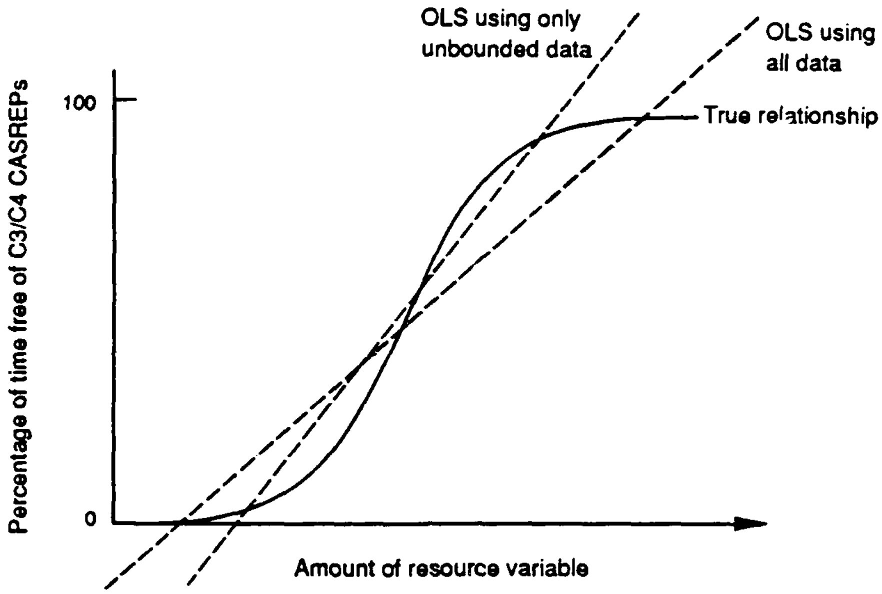

Figure A-2. OLS estimates of an S-shaped relationship

Using all the observations will generally result in an OLS coefficient that is too "steep" for the area near the bounds and too "flat" for values not near a bound. The estimate also causes predictions that extend into the infeasible ranges beyond the bounds. In other words, in the region well inside the two bounds, the coefficients generated are closer to zero than are the true coefficients, but these same estimated coefficients are greater than the true ones in the areas near the bounds.

Based solely on the figure, a regression that discards observations on either bound appears to reduce the bias problem. In reality, however, this only makes the bias more complex. The OLS estimate will still tend to overstate the slope at points near the bounds, but the estimate might overstate or understate the relationship at interior points. In addition, this method requires the discarding of some observations with a resulting loss of otherwise useful information.

TOBIT ESTIMATES

A more appropriate estimation method is the Tobit model, which is specifically designed for this type of data. A two-bounded Tobit will, in essence, estimate an S-shaped relationship that

asymptotically approaches each of the two bounds. As such, the impact of each independent variable can vary with changes in that variable (or with changes in other independent variables).[1]

To fully appreciate a Tobit model, it is necessary to imagine a hypothetical latent variable identical to PCTFREE except for being capable of assuming values beyond the bounds. Such a variable captures the same aspects of material condition that are captured by PCTFREE but is not limited by the two bounds. Denote this hypothetical variable PCTFREE*. One way to conceptualize PCTFREE* is to think of two ships (A and B) in a given month. Assume that ship A was in very good material condition and had no CASREP time that month. Assume that ship B also had no CASREP time that month, but its material condition was not nearly as good. In fact, assume that B's material condition was just barely good enough to result in no CASREPs.

PCTFREE is equal to 100 for each ship because neither had any CASREPs. In this case, PCTFREE* also takes on a value of 100 for ship B but, because ship A was in better condition than it had to be to reach 100 percent time free, PCTFREE* assumes a value greater than 100 for ship A.

OLS treats PCTFREE as a linear function of the independent variables, but a Tobit specification essentially treats the latent variable PCTFREE* as a linear function of the independent variables. Between the two bounds, the latent variable takes on the same value as PCTFREE. Values of the latent variable beyond the bounds are inferred by assuming a normal density.

Let Z_i denote row vectors of observations for ship i and let β denote the corresponding row vector of unknown coefficients. The stochastic specification of the two-bound Tobit for percentage of time free is then:

$$
\begin{aligned}
PCTFREE &= 0 \text{ if } PCTFREE^* \leq 0 \\
&= PCTFREE^* \text{ if } 0 < PCTFREE^* < 100 \\
&= 100 \text{ if } PCTFREE^* \geq 100.
\end{aligned}
$$

The expected value of PCTFREE, given that the latent variable is between the two bounds, is simply

$$\beta' Z_i + \sigma\Phi^* \ ,$$

1. This research has not attempted to test the assumption, found in both OLS and Tobit models, of normality for the error terms. Research is ongoing both on alternative estimators and on methods for testing for this type of misspecification (see [A-1]). Assuming another specific distribution does not necessarily solve the problem (and may, indeed, make it worse), the hope is that an estimator will eventually be devised that is both computationally tractable and robust to changes in the distribution.

where Φ^* is a nonlinear term that involves the density and distribution functions of a normal distribution evaluated at each of the two bounds and σ is the variance of the residuals from the estimation. (The specific formula is presented in the following section.)

INTERPRETATION OF TOBIT ESTIMATES

The One-Limit Tobit (CASDAYs)

Because a Tobit model treats the latent variable as a linear function of the explanatory variables, the expected value of the latent variable (in this case, CASDAYs*) is simply:

$$E(CASDAYs^*_i) = \beta' Z_i \ ,$$

where Z_i is the vector of values of the explanatory variables for observation i and β is the set of coefficients estimated by the Tobit model.

The expected value of actual CASDAYs (for any given values of the independent variables) is simply the expected value of CASDAYs* (given it is greater than zero) times the probability that the value of CASDAYs is, in fact, greater than zero.[1]

$$\begin{aligned} E(CASDAYs_i) &= \left(\beta' Z_i + \sigma \frac{\phi}{\Phi}\right)\Phi \\ &= \beta' Z_i \Phi + \sigma\phi \ , \end{aligned}$$

where Φ is the cumulative density of a standard normal distribution evaluated at $\frac{\beta' Z}{\sigma}$ and ϕ is the corresponding ordinate of the normal. As before, σ is the estimated standard deviation of the latent variable.

The partial derivatives of the function are the estimated effects of changes in the values of the various independent variables. Because of the Φ and ϕ terms, the value of each partial derivative varies with the values assumed by each of the independent variables.

$$\frac{\partial E(CASDAYs)}{\partial Z_j} = \Phi\beta_j \ .$$

Again Φ is evaluated at the appropriate $\frac{\beta' Z}{\sigma}$.

For example, in the case of the FF-1052s, $\beta' Z = 6.1$ when all right-side variables are equal to their respective means, and $\sigma = 21.3$.

1. In a general Tobit framework, the limit might be something other than zero. In those cases, an additional term is required. See [A-2] for details. The authors thank Professor William Greene, New York University, for help with these interpretations.

The expected CASDAYs for an FF-1052 with all right-side variables at their means is therefore:

$$E(CASDAYs) = (6.1)\Phi + (21.3)\phi \ .$$

With Φ and ϕ evaluated at $6.1 \div 21.3 = 0.286$,

$$\Phi = 0.613,$$

$$\phi = 0.383.$$

Thus,

$$E(CASDAYs) = (6.1)(0.613) + (21.3)(0.383) = 11.9 \ .$$

The estimated effect of a change in a given right-side variable j is simply

$$\beta_j \Phi = \beta_j 0.613 \ .$$

Again, this assumes that $\beta' Z$ is calculated for all right-side variables at their means.

The Two-Limit Tobit (PCTFREE)

The structure of the two-limit Tobit model is identical to the one-limit, except for the added complication of the latent variable (PCTFREE*) assuming values beyond the upper limit of 100.

Thus, the expected value of PCTFREE (for given values of the independent variables) takes the form:

$$E(PCTFREE_i) = \beta' Z_i (\Phi_2 - \Phi_1) + \sigma(\Phi_1 + \Phi_2) - (1 - \Phi_2)100 \ ,$$

where the subscripts 1 and 2 refer to evaluation of the normal at the lower and upper limits, respectively.

This is simply the expected value of PCTFREE (given it is between 0 and 100) times the probability it is in that range, plus the upper limit (100) times the probability PCTFREE is at that limit.[1]

1. As with NEWCAS, if the lower limit were a value other than zero, an additional term would be required for the value of the lower limit times the probability of being at the lower limit.

The partial derivatives, in this case, have the form:

$$\frac{\partial E(PCTFREE)}{\partial Z_j} = \beta' Z_j(\Phi_2 - \Phi_1) \ ,$$

which, again, is the estimated impact of changes in the value of Z_j holding all other independent variables constant.

REFERENCES

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APPENDIX B

PARAMETER ESTIMATES

APPENDIX B

PARAMETER ESTIMATES

Tables B-1, B-2, and B-3 list the actual Tobit and OLS results for models of PCTFREE. The corresponding results for CASDAYs appear as tables B-4, B-5, and B-6.[1] Table B-7 provides the predicted distribution of PCTFREE from the fully specified Tobit models for *Spruance* and *Adams* class ships. A close examination of these tables reveals several interesting results not covered explicitly in the main text.

In the first two specifications, the constant term was suppressed so that all the ship dummy variables could be included. In the full specifications (that include the CO control variables), only the most significant CO controls were included (such that no additional CO control variable would be significant at the 0.05 level).[2] The coefficients estimated for the particular ships or COs are not of interest and are not reported. These variables were included in the specification only to see if the relationships among the variables of interest and the ship's material condition could be more sharply delineated if the estimation were conditioned on possible systematic differences among ships and COs.

Perhaps the most important results are that the parameter estimates are reasonably stable across the three specifications and that the impact of the variables on PCTFREE (table B-1) is consistent with the impact of the variables on CASDAYs (table B-3). Thus, if the estimates from one of the specifications in table B-1 suggest that a given event will increase PCTFREE, the other specifications from table B-1 predict a similar increase.

Further, any event that the models in table B-1 indicate will increase PCTFREE will also reduce the estimated CASDAYs in the specifications in table B-4. This result is important because it suggests that the phenomena being captured in the models are robust. In other words, slight changes in the form of the model do not appreciably alter the results, which, in turn, improves one's confidence in the implications drawn from the models.

Table B-7 lists 95-percent confidence intervals of average PCTFREE for a one-standard-deviation change in the levels of manning and new crew for the fully specified OLS models.[3]

---

1. A scale adjustment factor is provided for each Tobit regression. Multiplying the scale adjustment factor by the estimated Tobit coefficient yields the estimated slope (or marginal effect) of the resource variable at the mean of the data. Appendix A contains an explanation of how this adjustment factor was calculated as well as a discussion of how to calculate the marginal effects at other points in the data.
2. Control variables were created for each of the 150 or so COs in each ship class. Stepwise regression (for a model that included the ship control and resource variables) was then used to see if there was systematic variation in CASREP reporting by the COs. Only 10 COs in each ship class exhibited significantly different behavior (such that their CO control variables were included in the first specification).
3. Equivalent confidence intervals for Tobit models cannot be readily calculated, but, in this case, they are likely to be similar to OLS intervals near the mean of the historic data. The Tobit intervals would be significantly different for estimates near either 0 or 100 percent time free. One clear difference is that they would not be symmetric.

Each interval is essentially the 95-percent confidence band for the average PCTFREE if all the ships of that class had resources and explanatory variables at the levels indicated. This does not imply that 95 percent of the ships are expected to have PCTFREE in that range; rather, it implies that the average for the class is expected to be in that range.

Table B-1. PCTFREE: *Knox* class (FF-1052s)

	Specification 1		Specification 2		Specification 3	
Variable	OLS	Tobit	OLS	Tobit	OLS	Tobit
TIME_CO	.299 (1.59)	.509 (1.62)	.228 (1.18)	.397 (1.20)	.217 (1.20)	.417 (1.31)
PACIFIC	12.517 (.84)	13.933 (.51)	14.603 (.93)	17.794 (.60)	4.291 (1.39)	6.530 (1.19)
SH_UNDER, in hundreds	1.082 (1.34)	.898 (.66)	.762 (.91)	.316 (.22)	.384 (.45)	-.273 (-.18)
PNEW3	-.984 (-2.60)	-1.823 (-2.83)	-1.016 (-2.63)	-1.703 (-2.56)	-.665 (-1.70)	-1.139 (-1.65)
MSO	-1.756 (-1.04)	-3.828 (-1.28)	-1.421 (-.83)	-3.711 (-1.21)	-1.721 (-1.01)	-3.939 (-1.28)
MSO_SQ	.068 (1.25)	.135 (1.41)	.060 (1.09)	.139 (1.42)	.072 (1.33)	.151 (1.55)
MSO_CB divided by 10	-.008 (-1.48)	-.014 (-1.55)	-.007 (-1.33)	-.014 (-1.58)	-.008 (-1.59)	-.016 (-1.74)
GEF	14.996 (1.36)	35.839 (1.88)	21.128 (1.89)	47.355 (2.43)	8.897 (.85)	25.444 (1.34)
MANREQ	1.320 (3.37)	2.183 (3.31)	1.619 (4.18)	2.644 (3.98)	1.336 (4.22)	2.056 (3.67)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	-36.500 (-1.18)	-72.460 (-1.31)
Sigma	-	48.141 (22.94)	-	51.570 (22.79)	-	57.217 (22.60)
R^2_{adj}	.22	-	.14	-	.04	-
Degrees of freedom	545	545	555	555	589	589
Scale factor for slope at mean of data	-	.61	-	.60	-	.56

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

Table B-2. PCTFREE: *Spruance* class (DD-963s)

	Specification 1		Specification 2		Specification 3	
Variable	OLS	Tobit	OLS	Tobit	OLS	Tobit
TIME_CO	–.127 (-.63)	–.312 (-.78)	–.119 (-.57)	–.316 (-.74)	.195 (.98)	.323 (.76)
PACIFIC	8.522 (.74)	23.117 (1.02)	17.497 (1.35)	41.338 (1.55)	–10.403 (-2.76)	–23.172 (-2.84)
SH_UNDER, *in hundreds*	–.058 (–.07)	–.702 (–.42)	–.372 (–.39)	–1.303 (–.67)	.775 (.82)	1.567 (.77)
PNEW3	–1.744 (–3.78)	–3.483 (–3.76)	–.351 (–.71)	–1.160 (–1.13)	.140 (.28)	.065 (.06)
MSO	9.590 (4.51)	18.601 (4.44)	3.081 (1.40)	7.363 (1.64)	2.219 (1.05)	6.356 (1.41)
MSO_SQ	–.281 (–4.43)	–.555 (–4.42)	–.094 (–1.42)	–.236 (–1.74)	–.066 (–1.02)	–.199 (–1.45)
MSO_CB divided by 10	.026 (4.49)	.052 (4.52)	.009 (1.53)	.024 (1.92)	.006 (1.09)	.020 (1.58)
GEF	–18.849 (–1.542)	–29.693 (–1.16)	–10.167 (–.74)	–15.136 (–.51)	–25.006 (–1.96)	–51.698 (–1.83)
MANREQ	2.211 (5.29)	4.654 (5.40)	1.416 (3.20)	3.368 (3.64)	.702 (2.06)	1.757 (2.40)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	–9.993 (–.28)	–113.436 (–1.50)
Sigma	–	52.943 (18.47)	–	63.693 (18.19)	–	71.053 (18.01)
R^2_{adj}	.345	–	.136	–	.03	–
Degrees of freedom	447	447	457	457	481	481
Scale factor for slope at mean of data	–	.57	–	.49	–	.46

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

Table B-3. PCTFREE: *Adams* class (DDG-2s)

	Specification 1		Specification 2		Specification 3	
Variable	OLS	Tobit	OLS	Tobit	OLS	Tobit
TIME_CO	1.440	3.591	.622	1.759	.814	1.997
	(4.72)	(5.04)	(2.04)	(2.56)	(3.02)	(3.26)
PACIFIC[a]	–	–	–	–	6.143	16.473
					(1.30)	(1.56)
SH_UNDER, in hundreds	2.149	5.452	1.926	5.325	2.507	6.063
	(1.96)	(2.34)	(1.63)	(2.01)	(2.00)	(2.14)
PNEW3	–1.403	–2.377	–1.835	–3.490	–1.630	–3.203
	(–2.57)	(–2.01)	(–3.15)	(–2.65)	(–2.78)	(–2.36)
MSO	3.093	5.654	5.546	12.194	4.405	8.350
	(1.05)	(.93)	(1.71)	(1.72)	(1.45)	(1.22)
MSO_SQ	–.111	–.150	–.216	–.442	–.149	–.251
	(–1.04)	(–.69)	(–1.87)	(–1.75)	(–1.37)	(–1.03)
MSO_CB divided by 10	.013	.013	.026	.050	.016	.023
	(1.13)	(.57)	(2.10)	(1.86)	(1.32)	(.88)
GEF	–.959	–12.201	18.593	31.055	24.629	46.765
	(–.06)	(–.35)	(1.02)	(.80)	(1.53)	(1.29)
MANREQ	2.364	4.769	2.843	6.278	1.931	4.615
	(3.94)	(3.80)	(4.76)	(4.77)	(3.76)	(3.90)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	-164.784	-458.169
					(-3.379)	(-4.072)
Sigma	–	58.763	–	71.521	–	80.239
		(25.12)		(14.85)		(14.70)
R^2_{adj}	.407	–	.225	–	.149	–
Degrees of freeedom	313	313	323	323	341	341
Scale factor for slope at mean of data	–	.61	–	.52	–	.47

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

a. Because no ship in the sample changed from the Atlantic Fleet to the Pacific Fleet, it was not possible to include the control for PACFLT in the specifications containing ship control variables.

Table B-4. CASDAYs: *Knox* class (FF-1052s)

Variable	Specification 1 OLS	Specification 1 Tobit	Specification 2 OLS	Specification 2 Tobit	Specification 3 OLS	Specification 3 Tobit
TIME_CO	−.178 (−1.80)	−.243 (−1.77)	−.124 (−1.20)	−.180 (−1.24)	−.084 (−.89)	−.147 (−1.06)
PACIFIC	−3.114 (−.40)	−1.578 (−.13)	−4.603 (−.55)	−3.891 (−.29)	−1.970 (−1.21)	−2.721 (−1.13)
SH_UNDER, in hundreds	−.752 (−1.77)	−.702 (−1.17)	−.500 (−1.13)	−.291 (−.46)	−.291 (−.64)	−.011 (−.02)
PNEW3	.463 (2.33)	.745 (2.66)	.488 (2.39)	.681 (2.33)	.308 (1.50)	.430 (1.42)
MSO	−.134 (−.15)	.065 (.05)	−.381 (−.42)	−.028 (−.02)	−.435 (−.49)	.040 (.03)
MSO_SQ	.004 (.16)	−.001 (−.03)	.010 (.31)	−.004 (−.10)	.010 (.34)	−.008 (−.20)
MSO_CB divided by 10	−.00008 (−.03)	.0004 (.11)	−.0003 (−.12)	.001 (.24)	−.0004 (−.15)	.001 (.35)
GEF	−2.925 (−.50)	-9.416 (−1.13)	−7.944 (−1.33)	−16.687 (−1.95)	−2.217 (−.40)	−8.357 (−1.00)
MANREQ	−.526 (−2.56)	−.761 (−2.64)	−.746 (−3.64)	−1.045 (−3.58)	−.558 (−3.35)	−.762 (−3.11)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	64.604 (3.97)	73.986 (3.07)
Sigma	–	21.297 (26.28)	–	22.980 (26.10)	–	25.290 (25.90)
R^2_{adj}	.21	–	.12	–	.02	–
Degrees of freedom	545	545	555	555	589	589
Scale factor for slope at mean of data	–	.61	–	.62	–	.61

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

Table B-5. CASDAYs: *Spruance* class (DD-963s)

Variable	Specification 1		Specification 2		Specification 3	
	OLS	Tobit	OLS	Tobit	OLS	Tobit
TIME_CO	.004	.134	.186	.305	.010	.006
	(.04)	(.76)	(1.46)	(1.54)	(.08)	(.03)
PACIFIC	−19.818	−23.249	−21.589	−29.140	5.417	9.800
	(−3.01)	(−2.40)	(−2.72)	(−2.41)	(2.31)	(2.58)
SH_UNDER,	−.030	.194	.134	.577	−.848	−.993
in hundreds	(−.06)	(.27)	(.23)	(.64)	(−1.43)	(−1.05)
PNEW3	.801	1.433	−.290	.078	−.632	−.545
	(3.01)	(3.54)	(−.96)	(.17)	(−2.05)	(−1.10)
MSO	−5.523	−9.073	−1.293	−2.994	−.894	−2.553
	(−4.51)	(−4.96)	(−.96)	(−1.44)	(−.68)	(−1.21)
MSO_SQ	.156	.264	.030	.086	.017	.070
	(4.26)	(4.81)	(.75)	(1.37)	(.42)	(1.09)
MSO_CB	−.014	−.024	−.003	−.008	−.001	−.007
divided by 10	(4.15)	(−4.78)	(-.72)	(-1.45)	(-.35)	(-1.12)
GEF	9.234	12.925	3.124	3.799	13.167	24.426
	(1.31)	(1.14)	(.37)	(.27)	(1.66)	(1.83)
MANREQ	−1.306	−2.277	−.760	−1.548	−.268	−.711
	(−5.42)	(−6.04)	(−2.81)	(−3.62)	(−1.26)	(−2.07)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	53.917	91.752
					(2.45)	(2.58)
Sigma	–	23.571	–	29.885	–	33.744
		(22.52)		(22.24)		(22.03)
R^2_{adj}	.44	–	.17	–	.04	–
Degrees of freedom	447	447	457	457	481	481
Scale factor for slope at mean of data	–	.57	–	.54	–	.53

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

Table B-6. CASDAYs: *Adams* class (DDG-2s)

Variable	Specification 1 OLS	Specification 1 Tobit	Specification 2 OLS	Specification 2 Tobit	Specification 3 OLS	Specification 3 Tobit
TIME_CO	–.855 (–3.50)	–1.390 (–4.33)	–.238 (–.97)	–.518 (–1.61)	–.407 (–1.81)	–.734 (–2.44)
PACIFIC	–	–	–	–	–2.814 (–.72)	–5.923 (–1.11)
SH_UNDER, in hundreds	–3.465 (–3.94)	–4.097 (3.73)	–3.437 (–3.53)	–4.059 (–3.21)	–3.630 (–3.47)	–4.314 (–3.10)
PNEW3	1.556 (3.56)	1.543 (2.84)	1.830 (3.91)	1.992 (3.34)	1.409 (2.89)	1.601 (2.48)
MSO	1.415 (.60)	1.063 (.37)	.171 (.07)	–1.434 (–.44)	.417 (.16)	–.875 (–.26)
MSO_SQ	–.070 (–.85)	–.750 (–.73)	–.500 (–.05)	.044 (.38)	.034 (–.38)	.005 (–.04)
MSO_CB divided by 10	.007 (.78)	.009 (.80)	–.002 (–.17)	–.006 (–.51)	.004 (.43)	.003 (.20)
GEF	–4.268 (–.33)	–.411 (–.03)	–19.303 (–1.34)	–20.092 (–1.07)	–34.715 (–2.60)	–41.271 (–2.32)
MANREQ	–1.899 (–3.95)	–2.500 (–4.11)	–2.210 (–4.62)	–3.040 (–4.88)	–1.199 (–2.81)	–1.772 (–3.11)
Ship dummies	Yes	Yes	Yes	Yes	No	No
CO dummies	Yes	Yes	No	No	No	No
Constant	No	No	No	No	156.050 (3.84)	218.997 (4.09)
Sigma	–	30.334 (21.57)	–	36.132 (21.30)	–	41.685 (21.16)
R^2_{adj}	.461	–	.297	–	.143	–
Degrees of freedom	313	313	323	323	341	341
Scale factor for slope at mean of data	–	.72	–	.69	–	.65

NOTE: t-statistics in parentheses for OLS coefficients; asymptotic Z-statistics in parentheses for Tobit coefficients.

Table B-7. Predicted distribution of PCTFREE for changes in manning and crew rotation for DD-963s and DDG-2s

Resource level	Predicted value: Ships with above-average PCTFREE for class	Predicted value: Range of PCTFREE for half of all ships
DD-963s (predicted mean PCTFREE = 69.9)		
Predicted PCTFREE for means of all variables	50%	52-90
MANREQ		
One *SD* above mean	67%	64-100
One *SD* below mean	29%	36-74
PNEW3		
One *SD* above mean	40%	44-83
One *SD* below mean	59%	58-96
DDG-2s (predicted mean PCTFREE = 51.0)		
Predicted PCTFREE for means of all variables	50%	21-71
MANREQ		
One *SD* above mean	72%	44-83
One *SD* below mean	26%	19-59
PNEW3		
One *SD* above mean	38%	26-65
One *SD* below mean	59%	37-76

NOTE: *SD* = standard deviation.

The first line of table B-8 indicates that, if all FF-1052 class ships had their explanatory variables at the mean for the class, the expected average PCTFREE would be 67.1. The 95-percent confidence interval is approximately plus or minus 2.5 points for a range of 64.5 to 69.6.

The next four lines for FF-1052s show estimates when either manning or new crew is changed by one standard deviation with all other variables at their means. Because each reflects a situation further from the actual overall mean, the confidence intervals are wider than the first one reported.

As discussed in the text, the most striking individual results from the tables are the effects of manning. The less manning relative to requirements, and the higher the percentage of new

crew, the more CASDAYs and the less PCTFREE the ships will have. Each of these effects is quite strong statistically, particularly when controlling for the individual ships (specifications 1 and 2).

Table B-8. Confidence intervals for the estimated impact of manning and new crew in the fully specified OLS model

Resource level	Point estimate of PCTFREE	95% confidence interval for estimated coefficients
FF-1052s:		
Predicted PCTFREE for means of all variables	67.1	64.5 to 69.6
Manning		
One *SD* above mean	73.2	68.1 to 77.5
One *SD* below mean	60.9	56.6 to 65.3
PNEW3		
One *SD* above mean	63.4	59.7 to 67.2
One *SD* below mean	70.7	67.0 to 74.4
DD-963s:		
Predicted PCTFREE for means of all variables	69.7	67.0 to 72.3
Manning		
One *SD* above mean	81.5	76.4 to 86.7
One *SD* below mean	57.8	52.6 to 62.9
PNEW3		
One *SD* above mean	63.7	59.6 to 67.8
One *SD* below mean	75.6	71.5 to 79.7
DDG-2s:		
Predicted PCTFREE for means of all variables	52.5	49.0 to 55.9
Manning		
One *SD* above mean	62.6	56.5 to 68.7
One *SD* below mean	42.4	36.2 to 48.5
PNEW3		
One *SD* above mean	47.3	42.1 to 52.6
One *SD* below mean	57.6	52.4 to 62.8

NOTE: *SD* = standard deviation.

GEF and TIME_CO also play a role in CASREP rates, although the statistical significance of these variables was borderline. TIME_CO was a statistically significant covariate for the

Knox and *Adams* class ships, but GEF achieved only borderline statistical significance for the *Knox* class. In the fully specified OLS model in table B-1, the effect of an extra month as CO was estimated to increase PCTFREE by 0.3. Six months of additional time, therefore, would be expected to increase PCTFREE by almost 1.8 percent. An increase in a ship's GEF, other things equal, would also be expected to increase the PCTFREE. In that same OLS specification, a 10-percentage-point increase in GEF is associated with about 1.5 percent more time free of C3/C4 CASREPs.[1]

Controlling for the individual ships does have some impact on the estimates of other coefficients. In general, the estimated impact of other variables is magnified somewhat by controlling for individual ships, but none of the coefficients is altered drastically. In addition, the controls usually increase the statistical significance of the coefficient estimates.

The addition of controls for certain COs (specification 1) also improves the goodness of fit dramatically. In table B-4, the adjusted R^2 is raised from 0.12 to 0.21 by the inclusion of CO controls [for the DD-963 class (table B-5), the increase is even more dramatic, from 0.17 to 0.44]. Certain COs tend to report a relatively high level of new CASREPs, and others a relatively low level, month after month. This observation is supported by the analysis because the models predict this behavior even after controlling for individual ship effects, ship employment, and manning. More important, without CO controls, the coefficient on the TIME_CO variable is not significantly different from zero in either the percentage of time free or the CASDAYs model for the *Knox* class ships; when the outlier CO controls are included, however, these coefficients become significant. Unless the model controls for diversity among COs, CO differences tend to mask the beneficial effects of more CO experience.

Table B-9 shows the contribution of ship and CO controls to the goodness of fit of the PCTFREE model. The chi-square values indicate that the inclusion of the ship controls significantly improves the overall fit of the Tobit equation with or without the resource variables. The introduction of the CO controls further improves the fit of the model. As the table shows, these results apply to all three ship classes and are significant at the 0.01 level.

Finally, the Tobits fit the data better overall and, in the case of percentage of time free, tend to be associated with both stronger t-statistics and effectively bigger coefficients for most variables. In addition, the Tobit models always fit the data better at the boundaries. For example, the fully specified OLS model in table B-1 shows an estimated decrease of 0.98 percentage points in PCTFREE for a 1-percentage-point increase in the percentage of new crew. The corresponding Tobit (evaluated at the mean) estimates a decrease of 1.1 percentage points.

The difference in the estimated impact of variables, between Tobit and OLS specifications, is greater for PCTFREE models than it is for CASDAYs models but occurs in both. This is to be

1. A 10-percentage-point increase in GEF is a change of 0.10.

expected because CASDAYs is at its bound of zero in approximately one-third of the observations, whereas percentage of time free reaches its bounds of zero or 100 in nearly half the observations.[1]

Table B-9. Results of chi-square tests of the significance of including ship and CO controls in the *Tobit* model of PCTFREE

	FF-1052	DD-963	DDG-2
Inclusion of ship controls only	1,656 (34)	1,696 (24)	46 (18)
Inclusion of resource variables only	1,528 (9)	1,646 (9)	56 (9)
Addition of ship controls to resource variables	108 (34)	88 (24)	66 (18)
Addition of CO controls to ship controls and resource variables	72 (10)	128 (10)	110 (10)
Log likelihood of model	–2,822	–2,291	–1,069

NOTE: All chi-square statistics are significant at the 0.01 level. Degrees of freedom for each test are in parentheses.

The results for the DD-963 class (tables B-2 and B-5) are somewhat different from those for the FF-1052 class. In particular, the importance of controls for individual ships and COs are much greater for the DD-963s. For example, in table B-5 (total CASDAYs), being in the Pacific Fleet appears to result in significantly more CASDAYs if no ship controls are used. Once the controls are included, however, the effect becomes significantly negative. In addition, both the manning rate and crew turnover variables perform dramatically better in the more completely specified models, as do the overhaul variables. Thus, ship and CO differences have a major influence on the apparent effects of other variables for the DD-963s.

Even in the fully specified model, there are obvious differences between the results for the DD-963 class and FF-1052 class. The DD-963s showed no effect from GEF, TIME_CO, or total steaming hours, but months since overhaul (or commission) had a major impact on both CASDAYs and PCTFREE. The different pattern for the time since overhaul or commission may

1. See figures A-1 and A-2 and the associated discussion, in the previous section, for more details.

occur, in part, because the *Spruance* class, which showed significant effects, is much newer and many of those observations were based on time since commission, whereas all observations on the *Knox* and *Adams* classes were based on time since overhaul.

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